

# Energy-Based Model for Designing and Managing Water Resources in Park Green Space Irrigation

Maryam Javadinia<sup>1</sup>, Nahid Izanloo<sup>1</sup>, Hossein Yousefi<sup>2,\*</sup>, and Amirhossein Fathi<sup>3</sup>

<sup>1</sup> Department of Energy Engineering, Sharif University of Technology, Tehran, Iran

<sup>2</sup> School of Energy Engineering and Sustainable Resources, College of Interdisciplinary Science and Technology, University of Tehran, Tehran, Iran

<sup>3</sup> School of Mechanical Engineering, Shiraz University, Shiraz, Iran

\*Corresponding author: hosseinyousefi@ut.ac.ir

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Urban parks enhance livability but consume significant water for irrigation. This study proposes a linear programming model to optimize allocation from diverse sources (groundwater, rainwater, runoff, treated wastewater, greywater, potable water) and design storage/treatment capacities, factoring in precipitation, quality, vegetation needs, and park area. Applied to a 15,844 m<sup>2</sup> non-fruit tree park in Kermanshah, Iran, the model was tested across five scenarios with/without treatment/storage systems. Results show 85% groundwater reliance in unrestricted access (Scenario 1), risking depletion and subsidence, but alternatives reduce this by >80% in constrained cases (e.g., 56% greywater and 23% wastewater in Scenario 2; 60% wastewater in Scenario 3). Final storage of 29 m<sup>3</sup> ensures reliability, with operating costs lowest for groundwater but viable for alternatives (e.g., 70% greywater in Scenario 2). This tool aids planners in sustainable urban greening amid scarcity, aligning with SDGs 6 and 11.

**Keywords:** Urban park irrigation, Water scarcity, Linear programming, Levelized cost of water assessment, Sustainable water management, Alternative water sources

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## 1. Introduction

Water scarcity is a major concern for humanity. Only 3% of the Earth's freshwater is accessible for human use [1]. The World Water Development Report estimates that nearly 6 billion people will face water scarcity by 2050 [2]. This is driven by various factors, including:

- I. Economic development and population growth[3]
- II. Water resource contamination[4-6]

Given these challenges, water conservation has become increasingly important.

By 2050, urban water demand will rise significantly. To balance supply and demand, two main approaches exist[7]:

I. Developing new water sources: including groundwater extraction, dam construction, seawater desalination, and imports.

These methods are expensive, inaccessible in some areas, and have negative environmental impacts.

II. Conserving existing water resources: including optimizing water supply systems, using water-efficient appliances, promoting behavioral change, and reusing and recycling water.

These methods are more sustainable and cost-effective but require behavioral change and initial investment.

The choice of the appropriate approach depends on the economic, social, and environmental conditions of each region.

The Middle East, particularly Iran, faces significant environmental challenges due to water scarcity. This scarcity has devastating environmental consequences[7, 8]. Iran heavily relies on groundwater resources, which are being depleted at an alarming rate. By 2050, desalination of seawater may be the only viable option for accessing acceptable water resources[8-10]. Urban green spaces assume a pivotal role within intricate urban ecosystems[11, 12]. These spaces confer a multitude of benefits, encompassing the reduction of air pollution[13], the provision of cooling effects[14, 15], the mitigation of climate change[16-18], the enhancement of groundwater management and recovery[19], and the promotion of sustainable development[20]. Considering the significant role of urban green spaces in the physical and mental health of citizens, the importance and necessity of these spaces will become increasingly evident with population growth[21-23].

### 1.1. Urban Green Spaces: A Pillar of Sustainable Development in Growing Cities

Cities are the primary centers for achieving sustainable development [23-25]. Densifying cities, projected to house over 60% of the developing world's population by 2050[26], necessitate prioritizing urban green spaces (UGS) for their well-documented

contributions to citizens' physical and mental health[21, 22]. Ensuring equitable access to UGS, a cornerstone of bio-justice[13], becomes critical. Current per capita UGS provision in Iranian cities falls between 7 and 12 square meters, while research suggests a minimum requirement of 9 square meters per person. Factoring in the value of UGS's ecosystem services, the ideal green space per capita is closer to 50 square meters[27].

### 1.2. Water Consumption in Landscape Irrigation in Iran: Challenges and Solutions

In Iran, groundwater is a primary source for landscape irrigation. However, the use of groundwater for this purpose poses challenges such as groundwater depletion and water contamination. This paper examines these challenges and proposes alternative water sources and sustainable irrigation practices as potential solutions.

**Table 1.** Comparison of Different Water Use Optimization Strategies in Landscape Irrigation

Title	Description	References
Supplemental Resources	The utilization of alternative water resources, such as rainwater harvesting, wastewater reuse, greywater utilization, etc..., presents a sustainable solution to mitigate water scarcity and ensure water security for future generations.	[28-34]
Policy Implementation	Replacing non-native plants and trees with low water requirements. Letting water-intensive lawns dry out during warm months. Using appropriate irrigation schedules. Improving soil quality for better water infiltration and retention.	[35, 36]
Smartening	Efficient irrigation technologies, including drip irrigation and sensor-based water demand estimation, are crucial for sustainable park landscape management, especially in water-scarce regions.	[37-40]

### 1.3. Literature Review on Water Use Optimization in Landscape Irrigation

Numerous studies have been conducted on water management and conservation in landscape irrigation. These studies have explored various approaches to optimizing water use.

Table 1 presents a comprehensive overview of the diverse strategies investigated for optimizing water use in landscape irrigation.

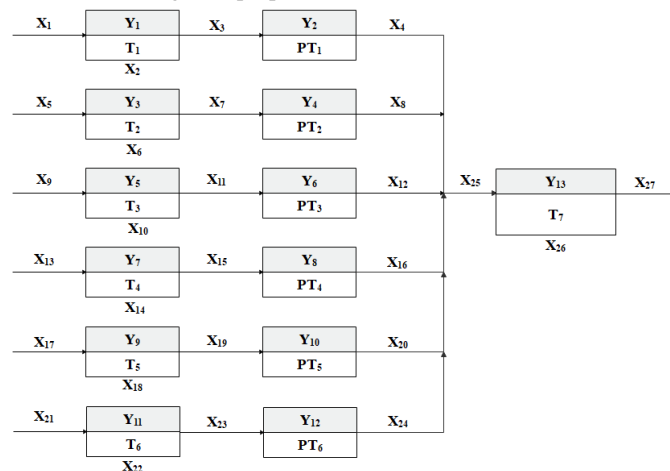
Pan et al. (2023) developed a novel Python-coded green space evapotranspiration and soil water budgeting model to estimate the irrigation requirements of urban green spaces in 286 Chinese cities[41]. Reyes-Paecke et al. (2019) used a comprehensive hydrological model to simulate soil moisture dynamics and estimate urban green space irrigation requirements[16]. Nahar et al. (2019) focused on modeling and optimizing runoff for urban green space irrigation[42].

Although previous studies have investigated alternative water sources and developed models for urban park irrigation, they have

not provided a comprehensive solution for optimal water resource management and sustainable landscape maintenance. This research fills this crucial gap by introducing a novel linear programming model that integrates recycled water, runoff runoff, and rainwater harvesting to optimize park irrigation. This innovative strategy can greatly enhance landscape irrigation management, promote water conservation, and safeguard water resources, particularly in conditions of water scarcity.

## 2. Water Supply Model for Urban Park Irrigation

This paper introduces a mathematical programming model for the optimal design and operation of a water supply system for urban park irrigation. The model accounts for various water sources, including potable water, groundwater, rainwater, runoff, greywater, and domestic wastewater. Notably, with the exception of greywater and wastewater, the other water sources typically require minimal or no treatment for irrigation purposes.



**Fig. 1.** Conceptual Diagram of the Water Supply Model for Urban Parks Irrigation

Figure 1 illustrates the proposed water supply model for parks. The model categorizes water sources into six groups: groundwater, potable water, domestic wastewater, greywater, rainwater, and runoff ( $X_1, X_5, X_9, X_{13}, X_{17}, \text{ and } X_{21}$ ).

In this study,  $X_i$  denotes the operating variables, with each set variable ( $X_i, i \in \{1, 2, \dots, 27\}$ ) comprising n variables. Meanwhile,  $Y_j$  represents planning variables, including storage tank capacities ( $T_\alpha, \alpha \in \{1, 2, \dots, 7\}$ ) and pre-treatment system capacities ( $PT_\beta, \beta \in \{1, 2, \dots, 6\}$ ).

To ensure a continuous water supply, a storage tank is incorporated after each source in the proposed system. This is essential due to the uncertainty of consistent access to various water sources. When multiple sources are available, the storage tank not only reduces the required capacity of the treatment system but also enhances the overall reliability of the water supply.

This study proposes an irrigation model that utilizes six water sources: groundwater, rainwater, runoff, domestic wastewater, greywater, and potable water from the public distribution network. Pre-treatment is applied to rainwater, runoff, and groundwater to ensure that water quality meets the standards required for irrigation. Potable water, assumed to be of high quality and safe for use, requires no treatment or pre-treatment. Domestic wastewater and greywater undergo treatment to remove contaminants, making them safe for irrigation purposes.

A water storage tank is incorporated into the system to address the variability in water availability and demand. The storage tank allows for the collection and storage of water from all sources, which can then

be used for irrigation when needed. The use of multiple water sources and a water storage tank provides a number of benefits, including:

- I. Increased water security
- II. Reduced water costs
- III. Environmental sustainability

The proposed model offers a sustainable and cost-effective solution for irrigation in regions where water resources are scarce or costly. A linear mathematical programming model is introduced to determine the optimal capacity and operation of a water distribution system for parks. The primary objective is to minimize the total system cost, encompassing both capital and operational expenses. The optimality criterion for design and operation is defined as minimizing the total system cost over the planning horizon. The model specifically targets non-fruit trees, which constitute the predominant green cover in parks.

### 2.1. Assumptions and Limitations

The problem is modeled based on the following assumptions:

- I. The recovery rate of water treatment and pre-treatment systems is independent of the influent flow rate.
- II. Annual demand remains constant.
- III. Operating costs are dependent on the extent of utilization of the purification and pre-treatment systems.
- IV. There is a direct linear correlation between capital costs and system capacity.
- V. Water demand is provided for the relevant time intervals.
- VI. The intervals of the time period are evenly distributed across the year.
- VII. The leakage rate of the water distribution system is negligible.
- VIII. The amount of water leakage from the storage tank is insignificant.
- IX. A zero discount rate has been assumed.
- X. The maintenance cost of storage tanks is assumed to be zero.
- XI. The price of water resources is not affected by the demand.
- XII. Although the quality of different water sources can still vary after treatment, the impact of this quality difference on green spaces and plants has been disregarded. It has been assumed that the treatment system for each water source will prepare the output water to the quality required for green spaces and plants.

### 2.2. Constraints

The technical constraints in this water resources optimization model are categorized into five distinct categories, namely:

- I. Capacity constraints on storage and treatment/pre-treatment systems
- II. Lower and upper bounds on decision variables
- III. Treatment/pre-treatment system
- IV. Storage system accumulation constraints
- V. Water inflow to the demand tank (tank 7)

Table 2 states constraints on the capacities. Where  $R_1$  to  $R_{13}$  represent the historical capacities of the systems, while  $X_i$  represents a set of operating variables ranging from  $(i-1)*n+1$  to  $i*n$ . Table 3 delineates the constraints governing the minimum water level in the tanks. These constraints are determined by factors such as requirement reliability, water demand, and resource scarcity.

The lower-bound constraints on the minimum water stored in the tanks are detailed in Table 3. Where  $Lb_i$  and  $Ub_j$  with  $i \in \{2,6,10,14,18,22,\text{and }26\}$ , represents receptivity a vector indicating the minimum and maximum water level in each tank at each time step. The minimum water level in each tank can vary at each time step. Additionally,  $Lb_{27}$  is a vector denoting the water demand at each time step.

The water level in the tanks at each time step is constrained by the conditions specified in Table 4.  $R_{\alpha-\phi}$ , where  $\alpha \in \{1,2,\dots,7\}$ , denotes the initial volume of water stored in each tank.

The water recovery through each pre-treatment system is addressed by the constraints outlined in Table 5. It is assumed that the recovery rate remains constant and is independent of the input rate, while the input quality remains unchanged. Where  $n_{PT,\beta}$ ,  $\beta \in \{1,2,\dots,6\}$ , represents the water recovery rate of each pre-treatment system.

**Table 2.** Constraints on the capacity of the systems

Tanks	Pre-treatment/purification	Final storage tank
$X_2 \leq y_1 + R_1$	$X_4 \leq y_2 + R_2$	
$X_6 \leq y_3 + R_3$	$X_8 \leq y_4 + R_4$	
$X_{10} \leq y_5 + R_5$	$X_{12} \leq y_6 + R_6$	$X_{26} \leq y_{13} + R_{13}$
$X_{14} \leq y_7 + R_7$	$X_{16} \leq y_8 + R_8$	
$X_{18} \leq y_9 + R_9$	$X_{20} \leq y_{10} + R_{10}$	
$X_{22} \leq y_{11} + R_{11}$	$X_{24} \leq y_{12} + R_{12}$	

**Table 1.** Minimum water level in the tanks

Minimum water level in tanks	Water demand	Lack of water resources
$X_2 \geq Lb_2$	$X_{27} \geq Lb_{27}$	$X_1 \leq Ub_1$
$X_6 \geq Lb_6$		$X_5 \leq Ub_5$
$X_{10} \geq Lb_{10}$		$X_9 \leq Ub_9$
$X_{14} \geq Lb_{14}$		$X_{13} \leq Ub_{13}$
$X_{18} \geq Lb_{18}$		$X_{17} \leq Ub_{17}$
$X_{22} \geq Lb_{22}$		$X_{21} \leq Ub_{21}$
$X_{26} \geq Lb_{26}$		

**Table 4.** Storage tank accumulation

Tank 1	$i \in \{2, \dots, n\}$	$x_{1*n+i} = x_{1*n+(i-1)} + x_i - x_{2n+i}$
		$x_{n+1} = R_{1-0} + x_1 - x_{2n+1}$
Tank 2	$i \in \{2, \dots, n\}$	$x_{5n+i} = x_{5n+(i-1)} + x_{4n+i} - x_{6n+i}$
		$x_{5n+1} = R_{2-0} + x_{4n+1} - x_{6n+1}$
Tank 3	$i \in \{2, \dots, n\}$	$x_{9n+i} = x_{9n+(i-1)} + x_{8n+i} - x_{10n+i}$
		$x_{9n+1} = R_{3-0} + x_{4n+1} - x_{6n+1}$
Tank 4	$i \in \{2, \dots, n\}$	$x_{13n+i} = x_{13n+(i-1)} + x_{12n+i} - x_{14n+i}$
		$x_{13n+1} = R_{4-0} + x_{12n+1} - x_{14n+1}$
Tank 5	$i \in \{2, \dots, n\}$	$x_{17n+i} = x_{17n+(i-1)} + x_{16n+i} - x_{18n+i}$
		$x_{17n+1} = R_{5-0} + x_{16n+1} - x_{18n+1}$
Tank 6	$i \in \{2, \dots, n\}$	$x_{21n+i} = x_{21n+(i-1)} + x_{20n+i} - x_{22n+i}$
		$x_{21n+1} = R_{6-0} + x_{20n+1} - x_{22n+1}$
Tank 7 (final)	$i \in \{2, \dots, n\}$	$x_{25n+i} = x_{25n+(i-1)} + x_{24n+i} - x_{26n+i}$
(Storage)		$x_{25n+1} = R_{7-0} + x_{24n+1} - x_{26n+1}$

$$\text{Input to the final storage tank: } x_{24n+i} = x_{3n+i} + x_{7n+i} + x_{11n+i} + x_{15n+i} + x_{19n+i} + x_{23n+i}$$

**Table 5.** Treatment system constraints

Pre-treatment 1:	$X_4 = \eta_{PT1} X_3$
Pre-treatment 2:	$X_8 = \eta_{PT2} X_7$
Pre-treatment 3:	$X_{12} = \eta_{PT3} X_{11}$
Pre-treatment 4:	$X_{16} = \eta_{PT4} X_{15}$
Pre-treatment 5:	$X_{20} = \eta_{PT5} X_{19}$
Pre-treatment 6:	$X_{24} = \eta_{PT6} X_{23}$

**2.3. Objective Function**

The objective function of this study aims to minimize the total cost associated with both investment and operation throughout a predefined planning horizon, denoted as  $n_1$ , as depicted by Equation (1). The planning horizon,  $n_1$ , is determined considering the varying lifetimes of system components. Specifically, it is defined as the least common multiple of the lifetimes of the treatment and pre-treatment components.

$$\text{Min Cost} = \text{OpEx} + \text{CapEx} \quad (1)$$

Where *OpEx* represents the operating costs incurred over a specified period, calculated by Equation (2), while *CapEx* denotes the capital expenses associated with system operation or upgrades over the same timeframe, estimated by Equation (3).

$$\text{OpEx} = n_1 * \left[ \sum_{k=1}^{27} \left( \sum_{i=1}^n (C_{(k-1)*n+i} * x_{(k-1)*n+i}) \right) \right] \quad (2)$$

$$\text{CapEx} = \sum_{j=1}^{13} \left( \frac{n_1}{LF_j} \right) (CapEx_j) * x_{27n+j} \quad (3)$$

Where  $n_1$  represents the planning horizon.  $C_{(k-1)*n+i}$  signifies the operating cost per unit of water at each stage, while  $x_{(k-1)*n+i}$  represents the value of the decision variable at each stage.  $\left(\frac{n_1}{LF_j}\right)$  denotes the number of times equipment  $j$  needs replacement over the planning horizon, and  $CapEx_j$  represents the capital cost associated with each unit of equipment  $j$ . Additionally,  $x_{27n+j}$  corresponds to system capacities ( $Y_1$  to  $Y_{13}$ ).

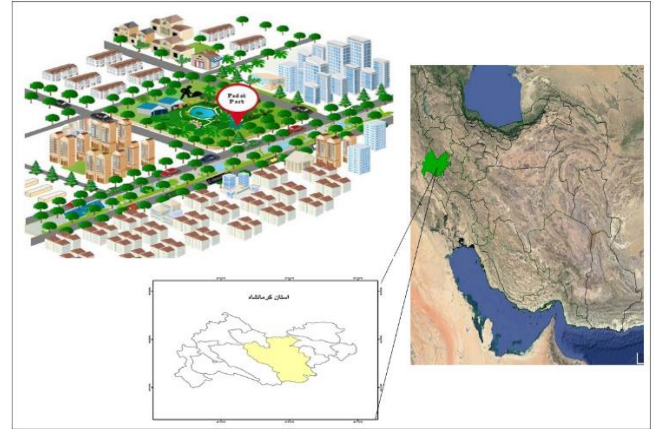
**3. Case study**

The semi-arid conditions of Kermanshah Province render it highly vulnerable to the consequences of climate change[43, 44]. Projected increases in seasonal temperatures and decreases in precipitation will likely intensify water scarcity and compromise the region's ecological balance[43, 45].

The per capita urban green space (UGS) in Iranian cities ranges from 7 to 12 square meters. Given the significance of ecosystem services provided by green spaces, an ideal allocation is approximately 50 square meters per person [27]. However, Kermanshah has a designated UGS of 11.7 square meters, indicating a considerable gap from international standards.

This study examines the irrigation water supply model for a 15,844 square meter urban park located in District 5 of Kermanshah Municipality. The complete dependence on groundwater resources for irrigation, due to the absence of surface water and graywater recycling systems, highlights the significance of this research in informing sustainable water management practices.

The park is located in a region with dense vegetation, which has led to a high-water demand in the area. This park was selected as a sample to evaluate the water supply model more accurately in conditions with high water requirements. Figure 2 shows the study area.



**Fig. 2.** Park in District Five of Kermanshah municipality, Iran

An analysis of climatic parameters in Kermanshah Province over a 10-year period revealed that winter precipitation suffices for the park's water requirements. The park's water demand in other seasons was estimated based on the average temperature and annual precipitation rate. The estimated water demand is 12 liters per square meter per day on hot days and 4 liters per square meter per day on temperate and cold days[46].

Due to a lack of adequate wastewater management infrastructure in the study area, graywater is commingled with other wastewater streams and disposed of collectively. This practice precludes the possibility of separate graywater sampling and quality assessment, and hinders the reuse of graywater for non-potable applications such as landscape irrigation.

**Table 6.** General Conditions for Water Supply in Parks Without Purification and Storage Systems

Equipment	Historical capacity ( $m^3/day$ )	Initial water storage capacity in tanks ( $m^3$ )	Service life (year)
<b>Groundwater:</b>			
Tank 1:	0	0	50
Pre-treatment system 1:	0	0	8
<b>Potable Water:</b>			
Tank 2:	0	0	50
Pre-treatment system 2:	0	0	50
<b>Domestic Wastewater:</b>			
Tank 3:	0	0	50
Pre-treatment system 3:	0	0	15
<b>Greywater:</b>			
Tank 4:	0	0	50
Pre-treatment system 4:	0	0	15
<b>Rainwater:</b>			
Tank 5:	0	0	50
Pre-treatment system 5:	0	0	8
<b>Runoff:</b>			
Tank 6:	0	0	50
Pre-treatment system 6:	0	0	8
<b>Final Storage</b>			
Tank 7:	0	0	50

### 4. Results

This study explores five scenarios for water supply in urban parks, aiming to guide urban managers in choosing suitable water sources and implementing effective strategies for sustainable water resources management. The scenarios are based on different conditions of water availability and treatment systems, considering sources such as potable water, groundwater, rainwater, runoff, greywater, and domestic wastewater.

The scenarios are included:

- I. Unrestricted Groundwater Access: Share of different water sources under unlimited access to groundwater.
- II. Restricted Groundwater Access: Role of alternative water sources when groundwater extraction is limited.
- III. No Groundwater Access: Suitable alternative water sources to meet park water requirements without groundwater access.
- IV. Low-Rainfall Year: Strategies for meeting park water requirements during low-precipitation periods.
- V. High-Rainfall Year: Share of different water sources in a year with abundant rainfall.

#### 4.1. Water Supply Model for Parks Without treatment and Storage Systems

This part of the study presents a water Supply Model for Parks Without Purification and Storage Systems. Therefore, historical capacities for all parts of the water supply system are considered to be zero.

Investment and operating cost analysis indicates that 29 cubic meters of storage space is sufficient to ensure the park's irrigation system functionality and prevent water shortages during hot days. Simulations demonstrate that water consumption optimization, implementation of purification and storage systems, and improved water resource management significantly enhance water supply to parks. The results obtained from various scenarios are presented subsequently.

Table 6 illustrates the assumed conditions of water supply in parks lacking water purification and storage systems.

Figure 3 illustrates the contribution of various water resources to green space irrigation under the five distinct scenarios. The analysis focuses on conventional water sources, including groundwater, rainwater, runoff, and potable water. The potential contributions of domestic wastewater and greywater are not considered in this assessment.

Scenario 1 demonstrates a high reliance on groundwater, with over 85% of green spaces in the region irrigated by groundwater sources. This poses a significant risk to the sustainability of these spaces, as water scarcity and climate change are expected to reduce groundwater availability in the coming decades[47-49].

Scenario 2 demonstrates a more sustainable approach than Scenario 1, where only 24% of the park's water requirements are met by groundwater and rainwater harvesting, due to limited groundwater availability and increasing water scarcity concerns[48, 50, 51].

To address the deficit, the use of alternative sources such as reclaimed wastewater or greywater is essential, which can reduce the reliance on freshwater resources and contribute to environmental sustainability[52-54].

Scenario 3 explores a hypothetical situation where there is no access to groundwater. This scenario highlights the critical importance of alternative water sources in ensuring the sustainability of green spaces. With average annual rainfall, only 8% of the park's water requirements can be met, underscoring the need for innovative solutions such as greywater and reclaimed

wastewater systems. The implementation of these alternative water sources can reduce the reliance on freshwater resources and contribute to the environmental sustainability of urban areas [52-54]. Scenario 4 investigates the impact of reduced rainfall and limited groundwater abstraction on park water sustainability. This scenario simulates a one-year period with these constraints, which are representative of potential future challenges in many regions due to climate change[55, 56]. Under these conditions, it is projected that less than 20% of a park's water needs can be met through groundwater and rainfall, highlighting the vulnerability of green spaces to water scarcity.

Scenario 5 investigates the potential impact of a hypothetical year with exceptional rainfall, exceeding the annual average by a significant margin. While rainwater harvesting and runoff collection could theoretically meet the park's water requirements in that specific year, this approach is not considered a viable long-term solution. The increasing frequency and intensity of flash floods associated with climate change pose a significant risk to such methods of water collection. Therefore, the identification of reliable and sustainable water sources for year-round supply remains a critical necessity for the long-term viability of parks and green spaces in a changing climate[35].

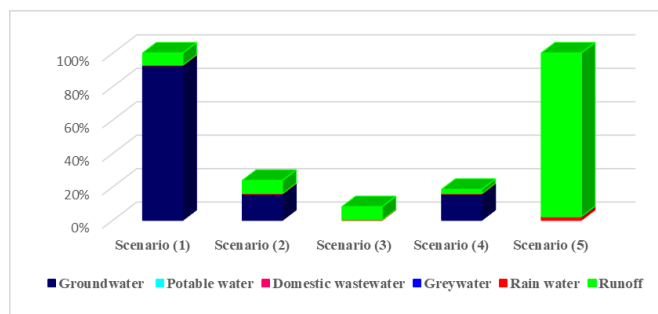


Fig. 3. Share of Each Water Source in Park Green Space Irrigation Excluding Greywater and Wastewater

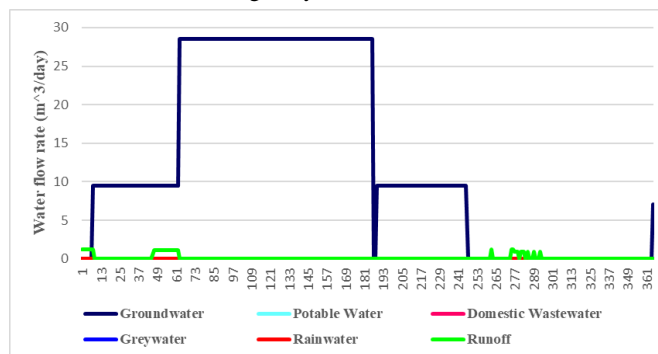


Fig. 4. Simulated Water Withdrawal Rates from Various Sources under Scenario 1 (for Parks without Storage and Treatment Systems)

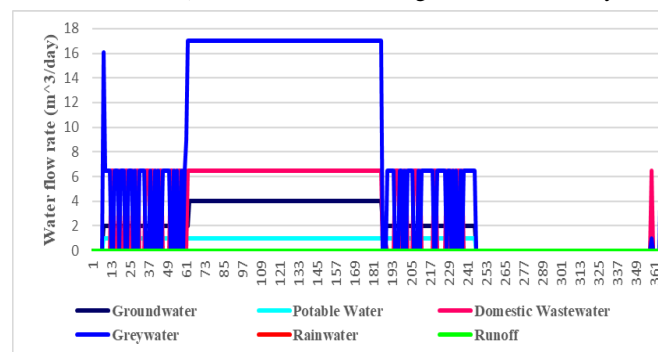


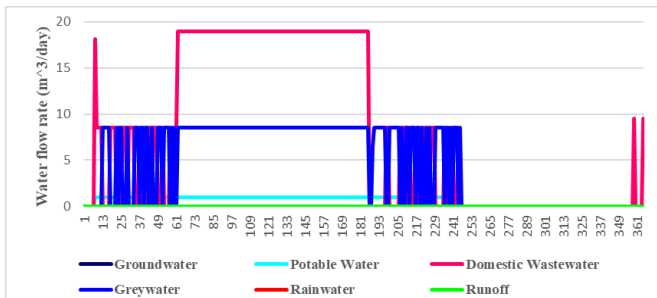
Fig. 5: Simulated Water Withdrawal Rates from Various Sources under Scenario 2 (for Parks without Storage and Treatment Systems)

### 4.1.1. Demand for different water sources

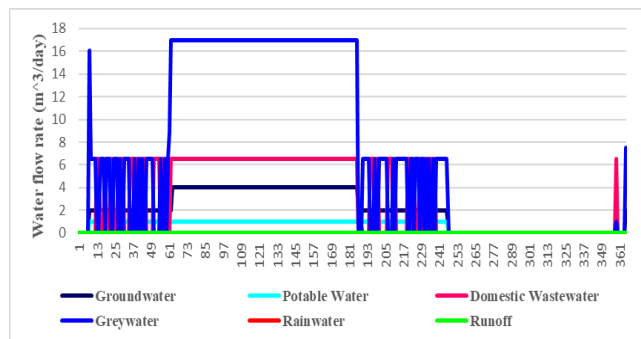
In the following, amount of water withdrawal rates from various sources are investigated.

#### Scenario 1: Unrestricted Groundwater Access

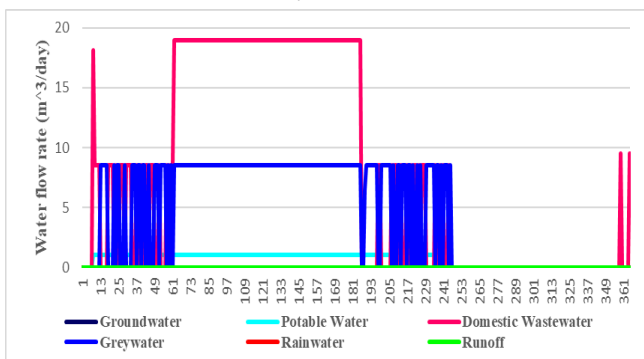
Figure 4 presents the simulated water withdrawal rates from various sources under Scenario 1, which assumes unrestricted access to groundwater.



**Fig. 6.** Simulated Water Withdrawal Rates from Various Sources under Scenario 3 (for Parks without Storage and Treatment Systems)



**Fig. 7.** Simulated Water Withdrawal Rates from Various Sources under Scenario 4 (for Parks without Storage and Treatment Systems)



**Fig. 8.** Simulated Water Withdrawal Rates from Various Sources under Scenario 5 (for Parks without Storage and Treatment Systems)

The model simulations propose the following water resources capacities for this scenario:

Groundwater: 28.5 m<sup>3</sup>/day, Runoff Harvesting: 1.17 m<sup>3</sup>/day, Final Storage Capacity: 29 m<sup>3</sup>

This scenario prioritizes groundwater as the primary water source. While the scenario indicates a substantial groundwater capacity, long-term excessive abstraction can lead to limited freshwater access:

#### Scenario 2: Restricted Groundwater Access

Figure 5 presents the simulated water withdrawal rates from various sources under Scenario 2 (restricted groundwater access)

In this scenario, groundwater access is constrained, with a maximum daily withdrawal of 2 m<sup>3</sup> during colder months and 4 m<sup>3</sup> during warmer months. Water sources: greywater 56%, wastewater treatment 23%, groundwater 16%, potable water 5%

Capacities: groundwater 4 m<sup>3</sup>, wastewater 6.5 m<sup>3</sup>, greywater 17 m<sup>3</sup>, potable water 1 m<sup>3</sup> (on some days)

Greywater and wastewater treatment are the main water sources. The contribution of groundwater and runoff is significantly reduced. If greywater is unavailable, the wastewater treatment capacity must increase to 23.5 m<sup>3</sup>/day.

#### Scenario 3: Absence of Groundwater

Figure 6 presents the simulated water withdrawal rates from various sources under Scenario 3 (Absence of Groundwater)

Water source distribution: greywater treatment 35%, wastewater treatment 60%, and potable water 5%. Water source capacities: Greywater treatment 8.5 m<sup>3</sup>, wastewater treatment 19 m<sup>3</sup>, potable water supply 1 m<sup>3</sup>, and final storage capacity 29 m<sup>3</sup>

If greywater is unavailable: wastewater treatment capacity increases to 27.5 m<sup>3</sup>/day.

Investment and operating costs: higher than Scenario 1.

Benefits: Mitigate water crises, safeguard groundwater, and promote long-term water sustainability.

Conclusion: despite the initial costs, scenario 3 is a viable solution for sustainable water management.

#### Scenario 4: Reduced Precipitation by One-Third

This scenario investigates the implications of a 33% reduction in annual average precipitation. The objective is to assess water withdrawals from various sources under conditions of severe precipitation scarcity.

Figure 7 presents the simulated water withdrawal rates from various sources under Scenario 4 (reduced precipitation by one-third)

In this scenario, the park's water requirements are met through a combination of reclaimed wastewater, greywater treatment, groundwater abstraction, and potable water. The specific proportions are as follows: Reclaimed wastewater 23%, Greywater treatment 56%, Groundwater abstraction 16%, and Potable water 5%.

Water Source Capacities: Based on model simulations, the following capacities are proposed for the different water sources in this scenario: Groundwater: 4 m<sup>3</sup>, Reclaimed wastewater 6.5 m<sup>3</sup>, Greywater 17 m<sup>3</sup>, Potable water 1 m<sup>3</sup>, Final storage capacity 29 m<sup>3</sup>.

Contingency Plan: In case greywater is unavailable, the reclaimed wastewater treatment capacity will be increased to 23.5 m<sup>3</sup>/day to compensate for the shortfall.

#### Scenario 5: Excessive Rainfall Analysis

This scenario examines the impact of excessive rainfall on the park's water requirements. Data for this scenario is derived from the study by Parandin et al.[46].

Key Assumptions:

5% of the runoff from District 5 of Kermanshah Municipality is collected.

25% of the direct rainfall in the park is collected.

Figure 8 presents the simulated water withdrawal rates from various sources under Scenario 5 (excessive rainfall analysis)

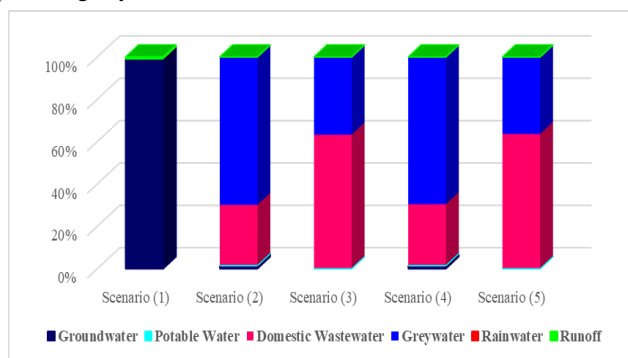
Water sources: Reclaimed wastewater 60%, Greywater treatment 34%, and Potable water 5%.

Modeled Capacities: Reclaimed wastewater treatment system 19

m<sup>3</sup>, Greywater treatment system 8.5 m<sup>3</sup>, Final storage capacity 29 m<sup>3</sup>. While rainwater and runoff harvesting can potentially meet the park's water requirements, storing large volumes of harvested water throughout the year is challenging, especially considering the uncertainty of rainfall due to climate change. Therefore, the developed water supply model suggests utilizing alternative methods such as reclaimed wastewater and greywater treatment, particularly during hot days of the year when rainfall is limited. Kermanshah province is highly vulnerable to climate change, making reliance on rainfall as the primary water source a high-risk strategy [44]. Analysis of climate change trends in Kermanshah City indicates a decrease in precipitation alongside increasing temperature, evaporation, and relative humidity [55]. It is projected that the province will experience the highest temperature increase and precipitation decrease by 2044 [45]. Therefore, the use of sustainable water sources such as wastewater and greywater are essential. Diversifying water supply sources and conducting thorough studies to select the best approach, considering the climatic conditions and water requirements of the park, are other necessary measures.

#### 4.1.2. Operating cost in each scenario

Figure 9 presents a comparative analysis of the operating costs associated with alternative water resources. The figure aims to facilitate the selection of an optimal water management strategy by providing key information to decision-makers.



**Fig. 9.** Comparison of Operating costs for Alternative Water Resources in Different Park Water Management Scenarios (for Parks without Storage and Treatment Systems)

Comparison of Operating costs for Alternative Water Resources in Park Water Management Scenarios

##### Scenario 1:

Water source: Groundwater abstraction

Operating costs: Low (electricity for pumping only)

Groundwater abstraction is not recommended as a sustainable water source for parks due to environmental risks such as land subsidence, groundwater depletion, and freshwater scarcity.

##### Scenario 2:

Operating costs: 70% greywater treatment, 29% reclaimed wastewater treatment, 1% groundwater abstraction

##### Scenario 3:

Operating costs: 63% reclaimed wastewater treatment, 37% greywater treatment

##### Scenario 4:

Operating costs: 69% greywater treatment, 29% reclaimed wastewater treatment, 1% groundwater abstraction

##### Scenario 5:

Operating costs: 64% reclaimed wastewater treatment, 36% greywater treatment

#### Analysis of Operating costs for Alternative Water Resources

##### Greywater:

Cheaper to treat than wastewater due to lower pollution [57, 58], Similar energy consumption for treatment as wastewater in Iran due to the lack of aeration control sensors

##### Groundwater:

Operating costs for groundwater are significantly lower than greywater and wastewater treatment.

Rainwater and runoff: Nearly zero due to no treatment requirement

##### Pre-treatment of Potable Water:

In practice, water can be used without treatment, only requiring pre-treatment. No additional operational cost for potable water treatment.

##### Symbolic Pre-treatment of Potable Water

Figure 1 depicts pre-treatment for potable water. However, this system functions more as a buffer. In other words, water merely passes through the pre-treatment system without undergoing any purification. Consequently, this symbolic pre-treatment system entails no additional operating costs for potable water treatment.

Although rainwater harvesting and runoff have negligible operating costs and are valuable resources, their use is entirely dependent on annual rainfall and park water requirements.

The simulated model suggests that utilizing a combination of treated wastewater and greywater is the best scenario for the park water supply. Despite the initial operational and investment costs, this approach can sustainably meet park water needs and contribute to the preservation and augmentation of freshwater resources.

#### 4.2. Water Supply System Modification for Parks with treatment and Storage Systems

The model can be applied for the parks with treatment and storage systems for modifying the current system. In these cases, there is no need to consider capital cost for the available systems and in this case, the capacity of existing technologies may simply be increased, or a new technology may be proposed for the water supply system, and the operation of the system may also be modified.

As shown in Table 7, the general conditions for optimizing water supply in parks with water treatment and storage systems are as follows

##### 4.2.1. Demand for different water sources

Figure 10, illustrates the share of usable water resources for irrigation in the park equipped with the storage and treatment systems under the general conditions provided in Table 7.

**Scenario 1:** 93% of the water demand is met through groundwater abstraction, and 7% is met through rainwater harvesting.

**Scenario 2:** access to groundwater is limited. Consequently, only 15% of the water demand is met through groundwater, and 8% is met through rainwater harvesting. To meet the remaining 77% of the park's water demand, the use of sustainable resources is essential.

**Scenario 3:** In this scenario, due to the lack of access to groundwater, rainwater and runoff harvesting can only meet 10% of the park's water demand. In contrast, the use of sustainable resources can meet 90% of the water demand under these conditions.

**Scenario 4:** A reduction in precipitation to one-third of the annual average and restrictions on groundwater abstraction reduce the contribution of these resources to meeting the park's water demand to 18%. Under these conditions, the use of unconventional and sustainable resources is essential.

**Scenario 5:** In this scenario, rainwater and runoff harvesting can

meet the park's water demand throughout the year if sufficient storage capacity is available. However, storing rainwater for the entire year is practically impossible due to spatial constraints. Under such circumstances, the use of sustainable resources such as greywater and wastewater become essential.

By implementing water storage and treatment systems and selecting the appropriate scenario, the contribution of sustainable resources to park landscape irrigation can be increased, thereby contributing to water conservation.

**Investigation of Scenario 1: Unlimited Access to Groundwater**

Figure 11 shows the flow rate of water extracted from different sources in Scenario 1 based on modeling and simulation.

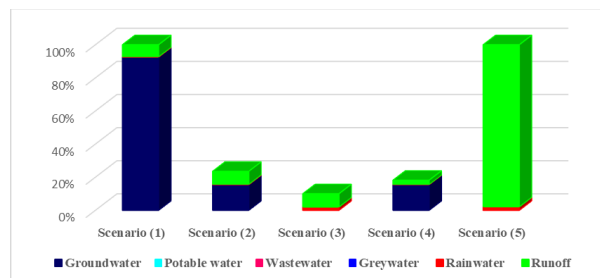
The study shows that there is no need to increase the existing capacity, except for increasing the final storage space from 20 to 29 cubic meters per day. Although 97% of the park's water demand is met by groundwater, continuous groundwater abstraction is highly detrimental and not recommended.

**Investigation of Scenario 2: Limited Access to Groundwater**

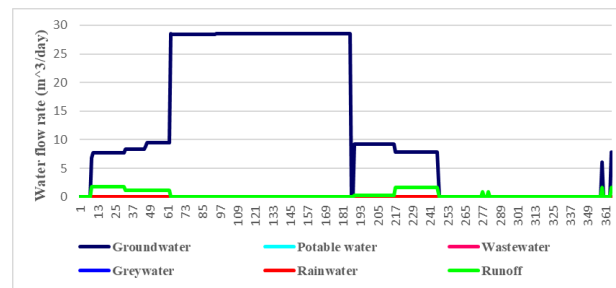
Figure 12 shows the flow rate of water extracted from different sources in Scenario 2 based on modeling and simulation.

**Table 7.** General Conditions of Water Supply Optimization in Parks with Water Treatment and Storage Systems

Equipment	Capacity (m <sup>3</sup> /day)	Initial water storage capacity in tanks (m <sup>3</sup> )	Service life (year)
<b>Groundwater:</b>			
Tank 1:	20	10	50
Pre-treatment system 1:	20	-	8
<b>Potable Water:</b>			
Tank 2:	3	1	50
Pre-treatment system 2:	3	-	50
<b>Domestic Wastewater:</b>			
Tank 3:	15	14.5	50
Pre-treatment system 3:	35	-	15
<b>Greywater:</b>			
Tank 4:	15	14.5	50
Pre-treatment system 4:	35	-	15
<b>Rainwater:</b>			
Tank 5:	10	2	50
Pre-treatment system 5:	10	-	8
<b>Runoff:</b>			
Tank 6:	10	4	50
Pre-treatment system 6:	10	-	8
<b>Final Storage</b>			
Tank 7:	20	20	50



**Fig. 10.** Share of Each Water Source in Park Green Space Irrigation Excluding Greywater and Wastewater (for Parks with Storage and Treatment Systems)



**Fig. 11.** Simulated Water Withdrawal Rates from Various Sources under Scenario 1 (for Parks with Storage and Treatment Systems)

In this scenario, 76% of the water demand is met by greywater treatment, 16% by groundwater abstraction, 3% by runoff, and 5% by potable water.

The model indicates that there is no need to increase the existing capacity, except for increasing the final storage space from 20 to 29 cubic meters per day.

**Investigation of Scenario 3: No Access to Groundwater**

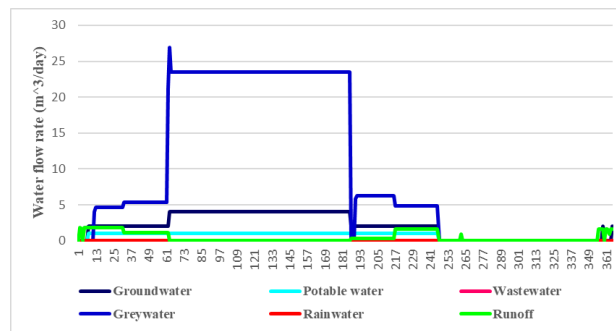
Figure 13 shows the flow rate of water extracted from different sources in Scenario 3 based on modeling and simulation.

In this scenario, 91% of the water demand is met by greywater treatment, 4% by runoff, and 5% by potable water.

The simulation shows that the current capacity is adequate, except for final storage, which requires an increase from 20 to 29 cubic meters per day.

**Investigation of Scenario 4: Reduction of Precipitation by One-Third**

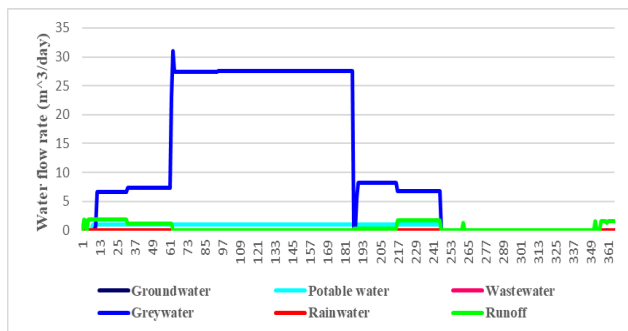
Figure 14 shows the discharge of water extracted from different resources in Scenario 4 based on modeling and simulation.



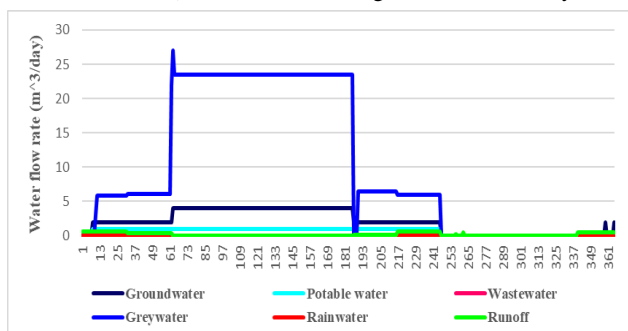
**Fig. 12.** Simulated Water Withdrawal Rates from Various Sources under Scenario 2 (for Parks with Storage and Treatment Systems)

In this scenario, 78% of water demand is met by greywater treatment, 16% by groundwater abstraction, 1% by runoff, and 5% by potable water. Simulations using the water supply model developed in this study indicate that the current park's capacities are sufficient to

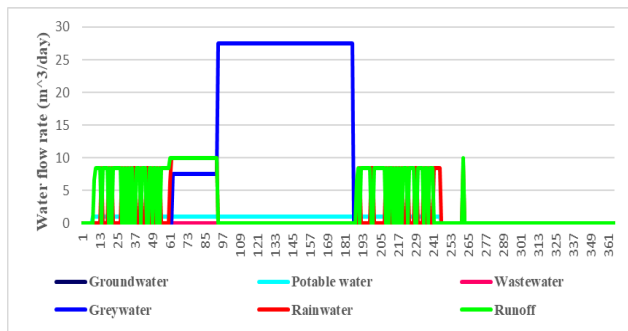
meet water demand under the conditions specified in Table 7. However, to enhance system sustainability and manage demand fluctuations, increasing the final storage capacity from 20 to 29 cubic meters per day is proposed.



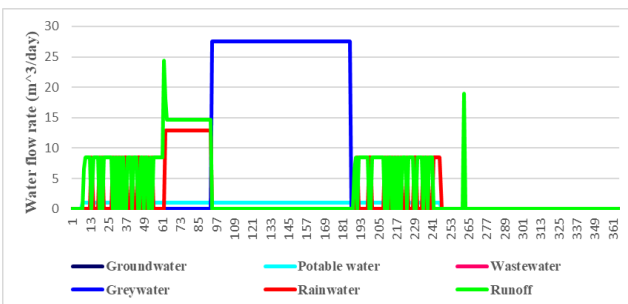
**Fig. 13.** Simulated Water Withdrawal Rates from Various Sources under Scenario 3 (for Parks with Storage and Treatment Systems)



**Fig. 14.** Simulated Water Withdrawal Rates from Various Sources under Scenario 4 (for Parks with Storage and Treatment Systems)



**Fig. 15.** Simulated Water Withdrawal Rates from Various Sources under Scenario 5 (for Parks with Storage and Treatment Systems)



**Fig. 16.** Impact of Rain and Run-off Water Storage Capacity Increase on Water Source Share. (for Parks with Storage and Treatment Systems)

**Investigation of Scenario 5: Above Average Precipitation**

Figure 15 shows the discharge of water extracted from different resources in this scenario based on modeling and simulation.

In this scenario, 60% of water demand is met by greywater treatment, 13% by rainwater harvesting, 21% by runoff harvesting, and 5% by potable water.

Increasing the runoff and rainwater storage capacity from 10 to 30 cubic meters per day enables the developed water supply model to increasingly meet its water demand from these sustainable and cost-effective sources. Figure 16 shows the model simulation results.

runoff and rainwater storage tank capacity from 10 to 30 cubic meters per day increases the share of this source in meeting the model's water demand by 40%.

The current capacity of the park's water storage and treatment system is sufficient for the initial treatment and storage of incoming water. However, modeling of the system has shown that increasing the final storage capacity from 20 to 29 cubic meters per day is necessary to meet the system's needs during peak demand and demand fluctuations.

**5. Future Directions**

This research is part of an ongoing project. The authors aim to conduct a sample study on an urban park or green space located within the university to examine: 1) the impact of adding another water source (recycled water from greenhouse irrigation) on the results of the model and reality, 2) the changes in the quality of input water from various sources on the quality of output water, and 3) the effect of treated water from different water sources on the green space.

**6. Conclusions**

This study developed a linear programming model to optimize irrigation for a 15,844 m<sup>2</sup> park in District 5, Kermanshah, Iran, integrating groundwater with alternative sources (rainwater, runoff, greywater, wastewater, potable water). Five scenarios were evaluated—with/without treatment/storage: (I) unrestricted groundwater, (II) limited withdrawal, (III) no groundwater, (IV) low-rainfall (one-third average), (V) high-precipitation—demonstrating over 80% groundwater reliance reduction in constrained conditions.

Scenario 1 highlights groundwater's cost-effectiveness (85% share, 28.5 m<sup>3</sup>/day, lowest OpEx), but risks depletion and subsidence. Scenarios 2-3 validate greywater (56% in Scenario 2; 35% in Scenario 3) and wastewater (23% and 60%, respectively) as viable substitutes, with potable water at 5% and final storage of 29 m<sup>3</sup> ensuring reliability. Scenario 4 (reduced rainfall) sustains demand with wastewater (23%) and greywater (56%), while Scenario 5 (high precipitation) leverages rainwater/runoff (up to 100%), requiring 29-30 m<sup>3</sup> storage amid climate variability.

A diversified strategy balances cost, supply, and environmental impact. Limitations include static recovery rates and greywater data gaps due to infrastructure, potentially skewing estimates. Future work: Integrate dynamic climate models, expand to multi-park networks, and enhance energy analyses to align with the 'energy-based' framework, as outlined in current research gaps. For planners, this model facilitates a shift to sustainable irrigation, leveraging results from scenarios that reduced groundwater reliance by over 80% in constrained conditions, supporting SDGs 6 (water) and 11 (cities).

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